

Proton Plan

Booster Corrector Upgrade

Baseline Review
August 2005

Presenter: Eric Prebys & Craig Drennan

- Brief review of what corrector magnets do.
- Specifications for the Corrector Upgrade Project.
- The scope and technical aspects of these projects.
- Management - Structure, man-power, schedule, costs ...
- What risks have been considered?
- Conclusions

- Purpose of corrector magnets
 - General:
 - Correct for errors due to imperfections in the focusing, defocusing, and bending magnets.
 - Chromaticity correction to cancel head-tail instabilities
 - Dipoles:
 - Control beam position.
 - Used in conjunction with collimation system to scrape beam halo
 - Used to help maintain precise aperture below extraction septum
 - Quadrupoles:
 - Maintain tune through cycle.
 - Cancel harmonic resonances.
 - Skew Quadrupoles:
 - Cancel coupled harmonic resonances.
 - Sextupoles:
 - Control chromaticity to damp head tail instability
 - Cancel harmonic resonances
 - Skew sextupoles:
 - Cancel harmonic resonances

- Each of the 48 sub-periods in the Booster has an (original) trim package, containing
 - Horizontal and Vertical trim dipoles
 - Low- β trims are operated DC
 - horizontal long straights
 - vertical short straights
 - Recently, the high- β trims were upgraded to be controlled by individual ramped current controllers
 - Horizontal short straights
 - Vertical long straights
 - Important for controlling losses
 - Normal and skew quadrupoles
 - Individual DC components for harmonic correction, added to
 - A common ramp (one for each type)
- In addition, there are ramped sextupole correctors at discrete locations (3 normal, 2 skew)
 - Work together with small number of DC sextupoles in a manner similar to the quads

- Trim dipoles
 - Inadequate strength or slew rate to control beam position throughout cycle
- Quadrupoles
 - Inadequate strength to hold constant tune through cycle
 - Inadequate slew rate at transition
- Sextupoles
 - Strength adequate
 - Discrete locations
 - Result in emittance blow up
 - Limit number of resonances which can be cancelled

- The Booster is susceptible to the following third order resonances:

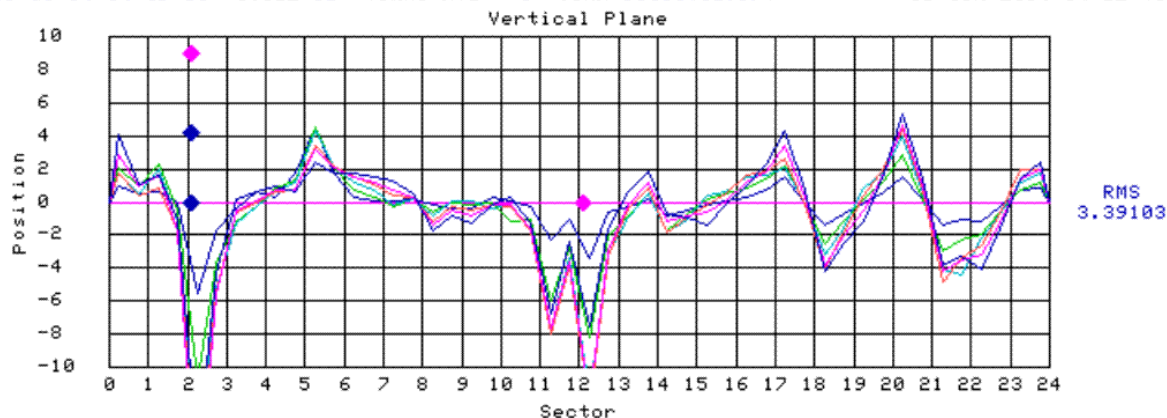
	$Q_x = 7$		$Q_y = 7$	
Correct with normal sextuples	\rightarrow	$3Q_x = 20$		$3Q_y = 20$
		$2Q_y - Q_x = 7$		$2Q_x - Q_y = 7$
		$2Q_y + Q_x = 20$		$2Q_x + Q_y = 20$
				Correct with skew sextuples

- We currently try to correct these with sextupoles at a few discrete point in the ring.
- Putting sextupoles at every period will greatly improve our ability to cancel these resonances.

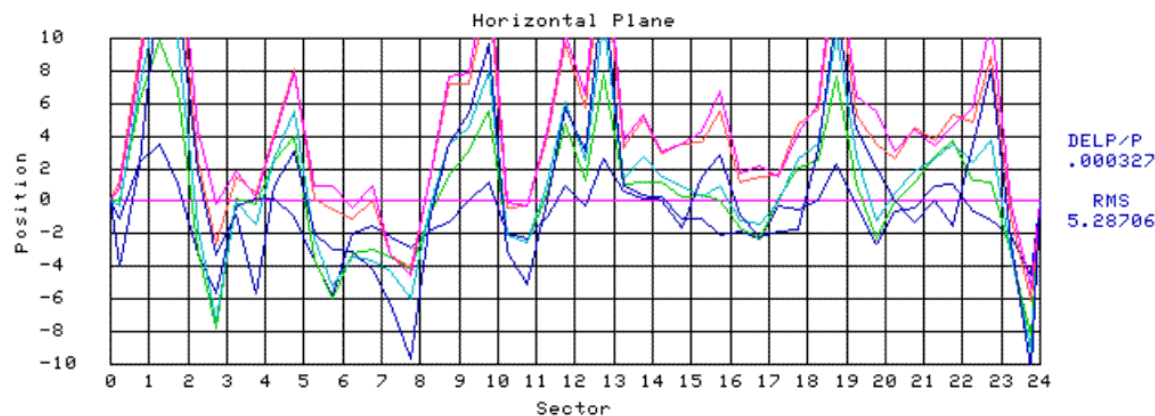
*See A. Drozhdin, "Fermilab Booster Dynamic Aperture Simulation with new Injection/Extraction Schemes", http://www-ap.fnal.gov/users/drozhdin/prdriver/pap_DINAM_APER.pdf

BOOSTER ORBIT

06/15/04 14:19:18 CYCLE 10 TURNS/AVG 8 TURN 18361(32.97) 15-JUN-2004 14:22:41



Vertical



Horizontal

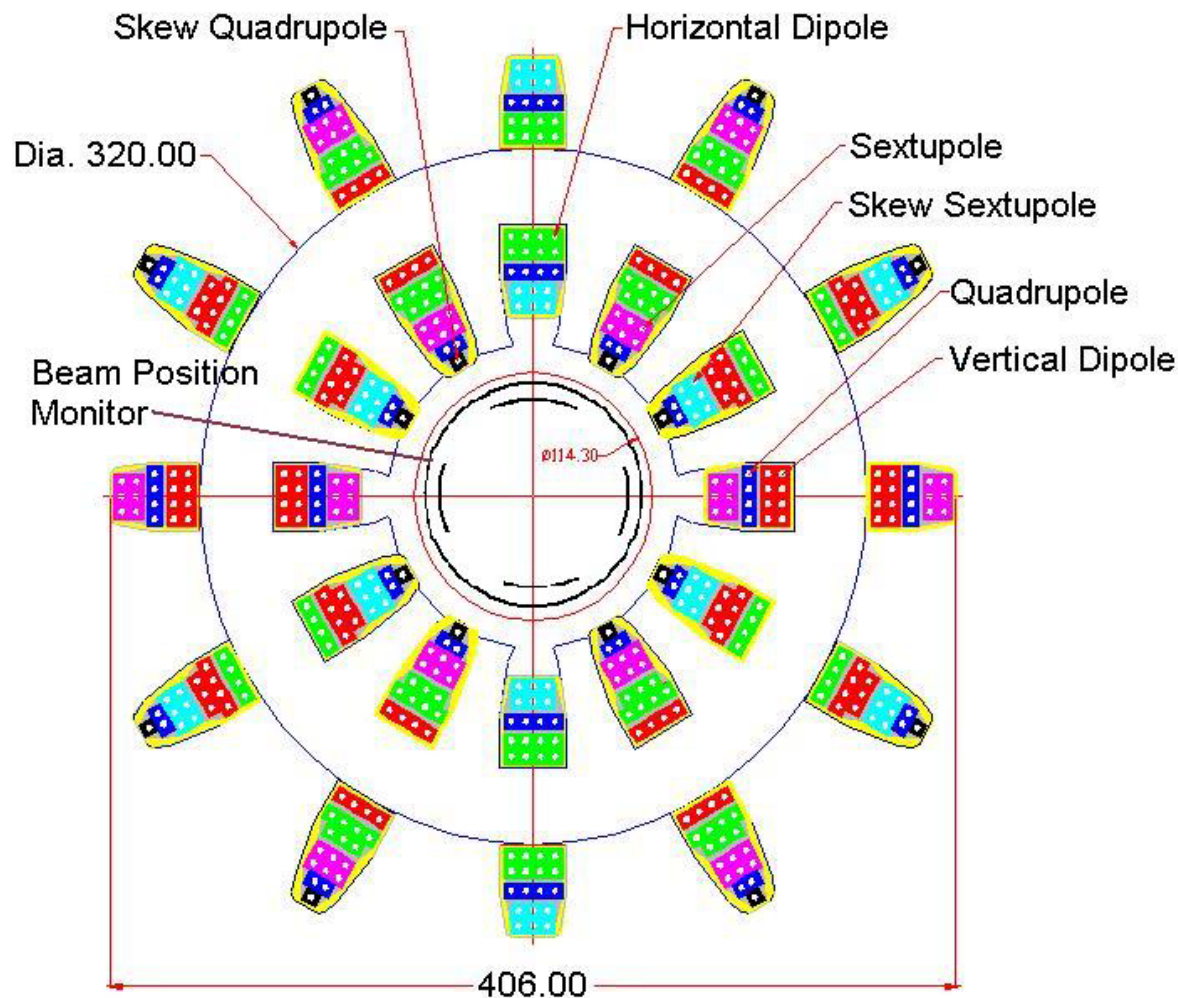
Beam Position at all periods around the ring relative to the position at injection.
Traces plotted for 5 ms intervals.

- Specifications for new corrector system:
 - Position Control:
 - Be able to produce 1 cm of beam motion at highest beam energy (8GeV).
 - Be able to slew position 1 mm/ms up to the middle of the cycle.
 - Correct observed beam motion
 - Work in conjunction with collimation system
 - Tune Control:
 - Maintain tune arbitrarily close to upper integer resonance throughout cycle.
 - Be able to switch from full field plus to full field minus in ~1 ms in order to rapidly switch tunes at transition time.
 - Sextupoles
 - Total strength consistent with existing system.
 - Increase slew rate
 - to full field minus in ~1 ms in order to rapidly switch chromaticity at transition time.

Magnet Parameter	Horz. / Vert. Dipole	Normal Quad	Skew Quadrupole	Normal / Skew Sextupole
Integrated Field	0.0175 T-m	0.16 T-m / m	0.0275 T-m / m	1.48 T-m / m ²
Maximum Peak Current	50 Amp	65* Amp	5 Amp	50 Amp
Integrated Field per Amp	87.5E-6 T-m / Amp	1.88E-3 T / Amp	5.5E-3 T / Amp	29.6E-3 T / m / Amp
Maximum Field Slew Rate	3.5 T-m / Sec	160 T / Sec	0.8 T / Sec	2,279 T / m / Sec
Magnet Inductance	7,840 μ H	1,104 μ H	6400 μ H	1,760 μ H
Magnet Resistance	0.27 Ohms	0.166 Ohms	0.35 Ohms	0.187 Ohms
Maximum Magnet Voltage, $V = L (dI/dt) + IR$	+/-92 Volts	+/-102 Volts	2.7 Volts	+/-145 Volts

- Control system specifications:
 - Ramped control of ALL (6x48) elements
 - Closed orbit position correction through cycle
 - Time dependent harmonic correction in addition to global multipole control

➤ New Multipole Corrector Package Design (Tech Division)



➤ New Magnet Power Supplies/Amplifiers

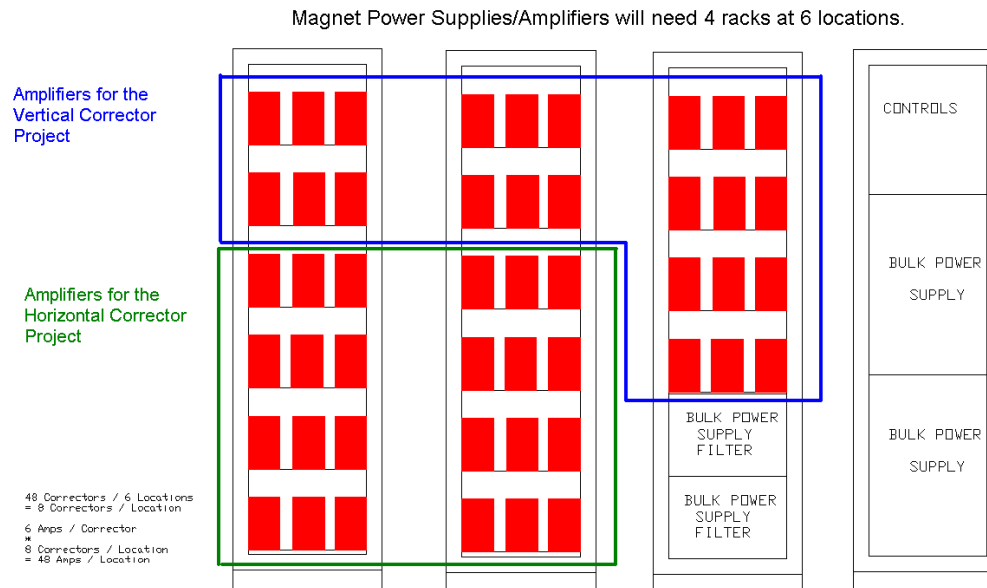
- Higher currents needed for higher magnet fields
- Higher voltages needed for faster slew rates.
- Investigating both an in house design and a suitable vendor product.
- Preliminary specifications available, [Beams-doc-1881, version 1](#) .

➤ New Power Supply Controls

- Will output ACNET programmable current reference curves for the power amplifiers.
- Will digitize current monitor outputs of amplifiers.
- Will compare current references to monitored current outputs to ensure tracking.
- Will provide digital Enable/Inhibit for power amplifiers.
- Will monitor digital status of the power amplifiers.
- Specifications available, [Beams-doc-1882, version 1](#) .

Meeting Goals

- New Racks and Cables for the Corrector System
 - Rack space and cable penetrations have been identified.
 - A booster floor plan has been marked up ([Beams-doc-1883, version 1](#)) to show the location of the new corrector magnets, new racks, and cable routing.



Elevation Sketch of Racks

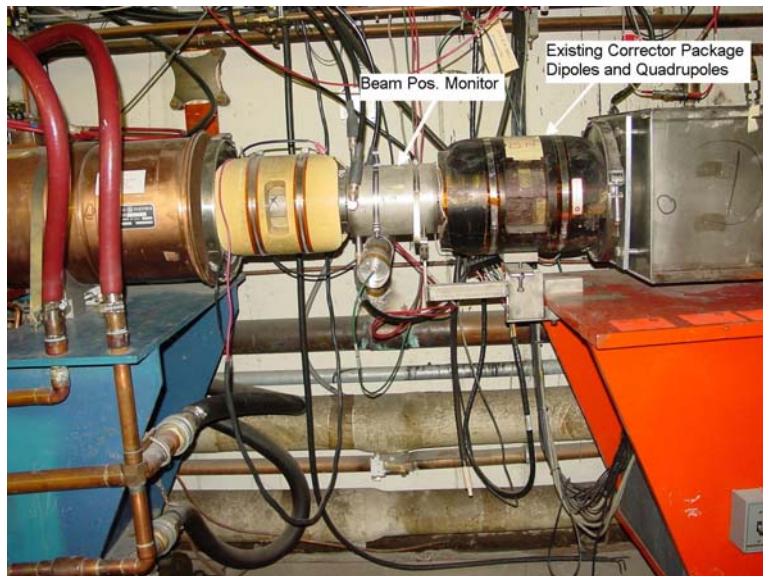
- New Plumbing for Corrector Package Cooling Water
 - Total water flow -- 1/2 GPM at 60 PSI water pressure drop.
 - Water temperature rise -- 20 C
- The current water system in the Booster is expected to be able to handle this additional load.

Magnet parameters:

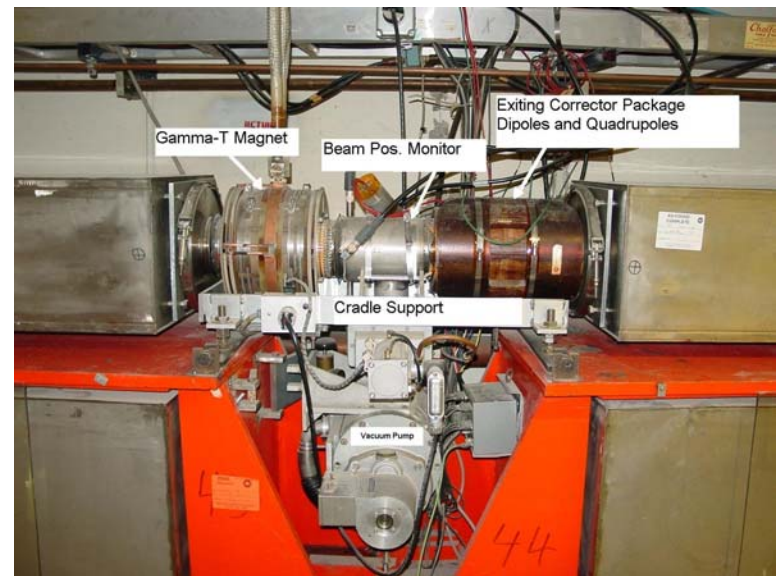
	The coil resistance	Nominal current	Power losses
Vertical Dipole	0.27 Ohm	49.6 A	665 W
Horizontal Dipole	0.27 Ohm	29.7 A	238 W
Normal Quadrupole	0.166 Ohm	42.5 A	300 W
Normal Sextupole	0.187 Ohm	47.75 A	426 W
Skew Quadrupole	0.042 Ohm	14.5 A	0.6 W
Skew Sextupole	0.187 Ohm	47.75 A	426 W

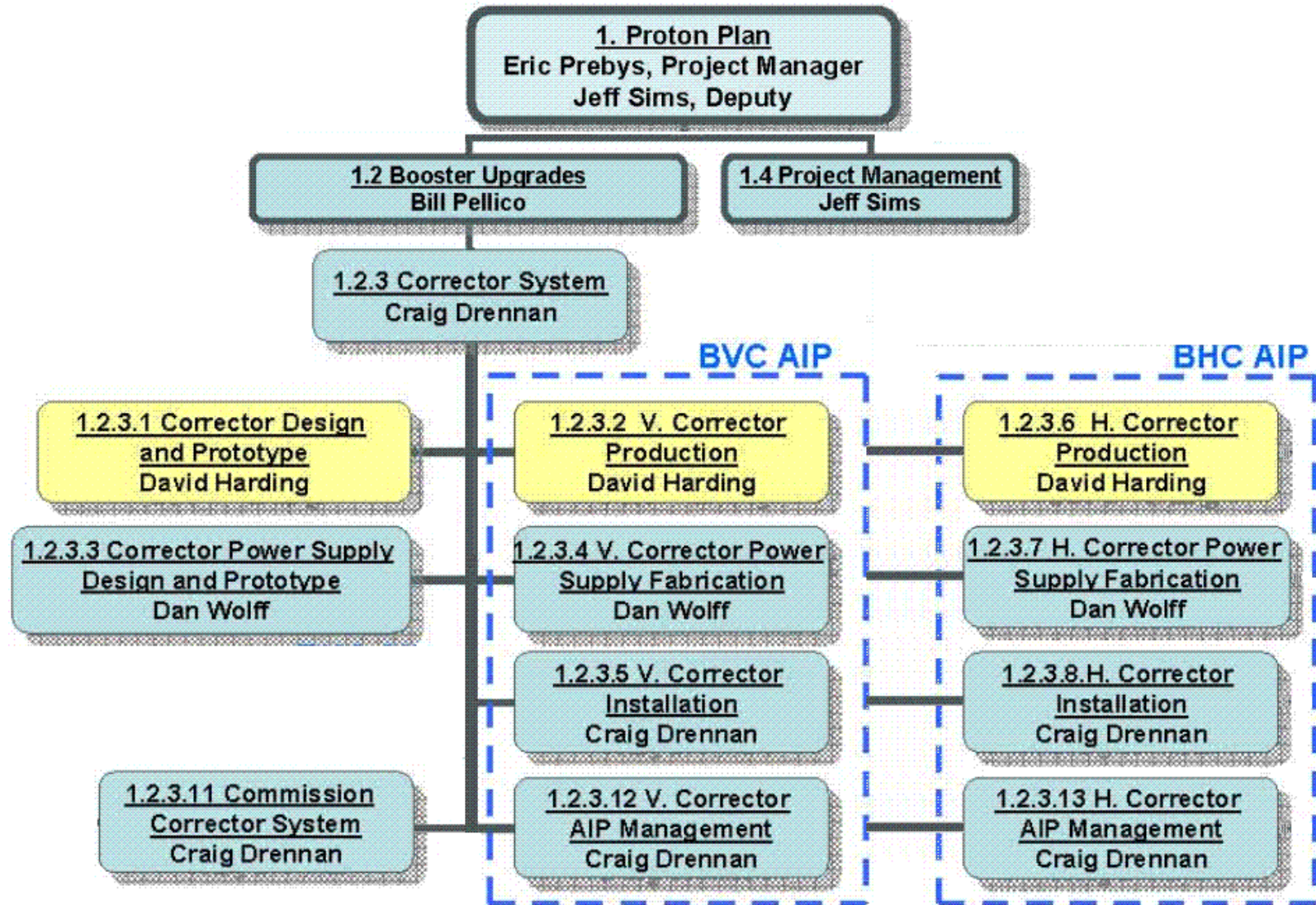
- New Magnet Supports and Long and Short Straight Spool Piece Designs
 - New corrector packages will also incorporate a beam position monitor.
 - New cradle supports in the short straights will be designed for the Horizontal Corrector project.
 - New Gamma-T Magnet may be included.

Booster Long Period 14



Booster Short Period 22





- **Manpower: People Doing the Work**

(Those who have assisted so far with estimates and design work, that I can remember and those I expect help from during the project)

- **Corrector System Specification**

- **AD - BS PROTON SOURCE**
- **Jim Lackey, Bill Pellico, Eric Prebys, Dave Harding (TD)**

- **Corrector Package Design, Prototyping and Evaluation**

- **TD - ENGINEERING & FABRICATION**
- **Dave Harding, TJ Gardner, Alexander Makarov, Vladimir Kashikhin**

- **Corrector Package Fabrication**

- **Outside Manufacturer**

- Manpower: People Doing the Work (cont.)
 - Power Supplies/Amplifiers Design, Prototyping and Evaluation.
 - AD-AS-ELECTRICAL/ELECTRONIC SUPPORT
 - Dan Wolff, et.al.
 - Power Amplifier Fabrication
 - Outside Manufacturer
 - CAMAC Power Supply Controllers
 - AD-ACCELERATOR CONTROLS DEPT
 - Allen Franck, et.al.
 - Pulling of Power and Control Cables
 - AD-BE-ENGINEERING SUPPORT
 - James Ranson, Estimates and Oversight
 - Contract Electricians

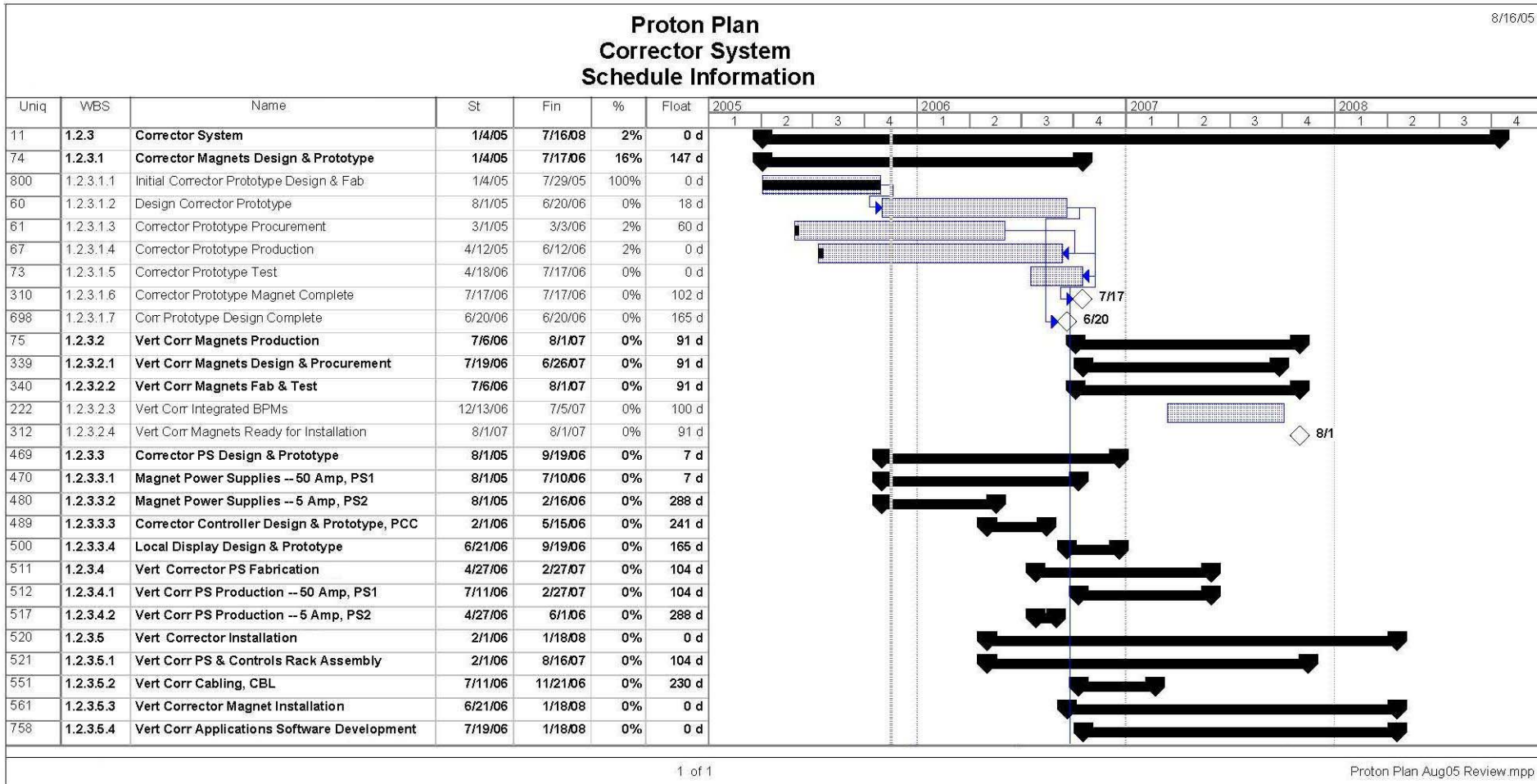
- Manpower: People Doing the Work (cont.)
 - Building Power Supply Racks, Cable Termination, Controls Installation.
 - AD-BS PROTON SOURCE
 - Craig Drennan, design and oversight
 - Doris Dick, Andrew Feld, Jeff Larson, Rich Meadowcroft
 - Magnet Cooling Water Installation
 - AD-AS-MECHANICAL SUPPORT DEPT
 - Maurice Ball, et.al.
 - New Magnet Supports and Long / Short Straight Spool Piece Designs
 - AD-AS-MECHANICAL SUPPORT DEPT
 - Joel Misek, Robert Reilly, et.al.

- Manpower: People Doing the Work (cont.)
 - Removal of Old Long / Short Straight Spool Piece and Assembly and Installation of the New Ones.
 - AD-AS-MECHANICAL SUPPORT DEPT
 - Danny Douglas, Ben Ogert, et.al.
 - Surveying and Alignment of New Correctors.
 - PPD-TECHNICAL CENTERS
 - Dr. O'Sheg Oshinowo, et.al.
 - Correctors and Power Supply Tests and Commissioning
 - AD-BS PROTON SOURCE
 - Craig Drennan, Jim Lackey, Bill Pellico, et.al.
 - Application Software Development
 - AD-ACCELERATOR CONTROLS DEPT
 - Brian Hendricks, Bill Marsh, Richard Neswold, James Patrick

WBS	Name	Esc SWF	Esc M&S	Cont %
1.2.3	Corrector System	\$1,813,563	\$2,764,371	45%
1.2.3.1	Corrector Magnets Design & Prototype	\$152,214	\$49,409	25%
1.2.3.1.1	Initial Corrector Prototype Design & Fab	\$62,742	\$15,000	0%
1.2.3.1.2	Design Corrector Prototype	\$43,373	\$0	40%
1.2.3.1.3	Corrector Prototype Procurement	\$5,290	\$34,409	40%
1.2.3.1.4	Corrector Prototype Production	\$40,809	\$0	40%
1.2.3.1.5	Corrector Prototype Test	\$0	\$0	0%
1.2.3.1.6	Corrector Prototype Magnet Complete	\$0	\$0	0%
1.2.3.1.7	Corr Prototype Design Complete	\$0	\$0	0%
1.2.3.2	Vert Corr Magnets Production	\$319,547	\$493,268	58%
1.2.3.2.1	Vert Corr Magnets Design & Procurement	\$21,727	\$78,810	40%
1.2.3.2.2	Vert Corr Magnets Fab & Test	\$284,593	\$374,075	60%
1.2.3.2.3	Vert Corr Integrated BPMs	\$13,227	\$40,383	60%
1.2.3.2.4	Vert Corr Magnets Ready for Installation	\$0	\$0	0%
1.2.3.3	Corrector PS Design & Prototype	\$140,684	\$26,728	40%
1.2.3.3.1	Magnet Power Supplies -- 50 Amp, PS1	\$75,773	\$10,794	40%
1.2.3.3.2	Magnet Power Supplies -- 5 Amp, PS2	\$32,544	\$2,056	40%
1.2.3.3.3	Corrector Controller Design & Prototype, PCC	\$19,102	\$12,336	40%
1.2.3.3.4	Local Display Design & Prototype	\$13,265	\$1,542	40%
1.2.3.4	Vertical Corrector PS Fabrication	\$42,080	\$499,608	40%
1.2.3.4.1	Vert Corr PS Production -- 50 Amp, PS1	\$36,931	\$462,600	40%
1.2.3.4.2	Vert Corr PS Production -- 5 Amp, PS2	\$5,149	\$37,008	40%
1.2.3.5	Vertical Corrector Installation	\$225,387	\$266,253	40%
1.2.3.5.1	Vert Corr PS & Controls Rack Assembly	\$65,668	\$124,376	40%
1.2.3.5.2	Vert Corr Cabling, CBL	\$15,075	\$61,920	40%
1.2.3.5.3	Vert Corrector Magnet Installation	\$48,240	\$79,957	40%
1.2.3.5.4	Vert Corr Applications Software Development	\$96,405	\$0	40%

WBS	Name	Esc SWF	Esc M&S	Cont %
1.2.3.6	Horiz Corr Magnets Production	\$319,547	\$493,268	58%
1.2.3.6.1	Horiz Corr Magnets Design & Procurement	\$21,727	\$78,810	40%
1.2.3.6.2	Horiz Corr Magnets Fab & Test	\$284,593	\$374,075	60%
1.2.3.6.3	Horiz Corr Integrated BPMs	\$13,227	\$40,383	60%
1.2.3.6.4	Horiz Corr Magnets Ready for Installation	\$0	\$0	0%
1.2.3.7	Horizontal Corrector PS Fabrication	\$42,080	\$499,608	40%
1.2.3.7.1	Horiz Corr PS Production -- 50 Amp, PS1	\$36,931	\$462,600	40%
1.2.3.7.2	Horiz Corr PS Production -- 5 Amp, PS2	\$5,149	\$37,008	40%
1.2.3.8	Horizontal Corrector Installation	\$238,681	\$256,754	40%
1.2.3.8.1	Horiz Corr PS & Controls Rack Assembly	\$65,668	\$124,376	40%
1.2.3.8.2	Horiz Corr Cabling, CBL	\$15,075	\$61,920	40%
1.2.3.8.3	Horiz Corrector Magnet Installation	\$61,533	\$70,458	40%
1.2.3.8.4	Horiz Corr Applications Software Development	\$96,405	\$0	40%
1.2.3.9	Commission Corrector System	\$77,220	\$0	0%
1.2.3.10	Corrector System Complete	\$0	\$0	0%
1.2.3.10	Vert Corr AIP Project Management	\$44,453	\$0	40%
1.2.3.11	Horiz Corr AIP Project Management	\$36,282	\$0	40%
1.2.3.12	Prepare AIP Documentation	\$27,567	\$0	40%
1.2.3.13	Corrector System Technical Review	\$0	\$0	0%
1.2.3.14	Corrector AIPs Approved	\$0	\$0	0%
1.2.3.15	Review Booster Modifications Design	\$0	\$0	0%
1.2.3.16	Corrector System Installation Review	\$0	\$0	0%
1.2.3.17	Corrector Magnets Spares Account (12 spares)	\$147,822	\$179,475	40%

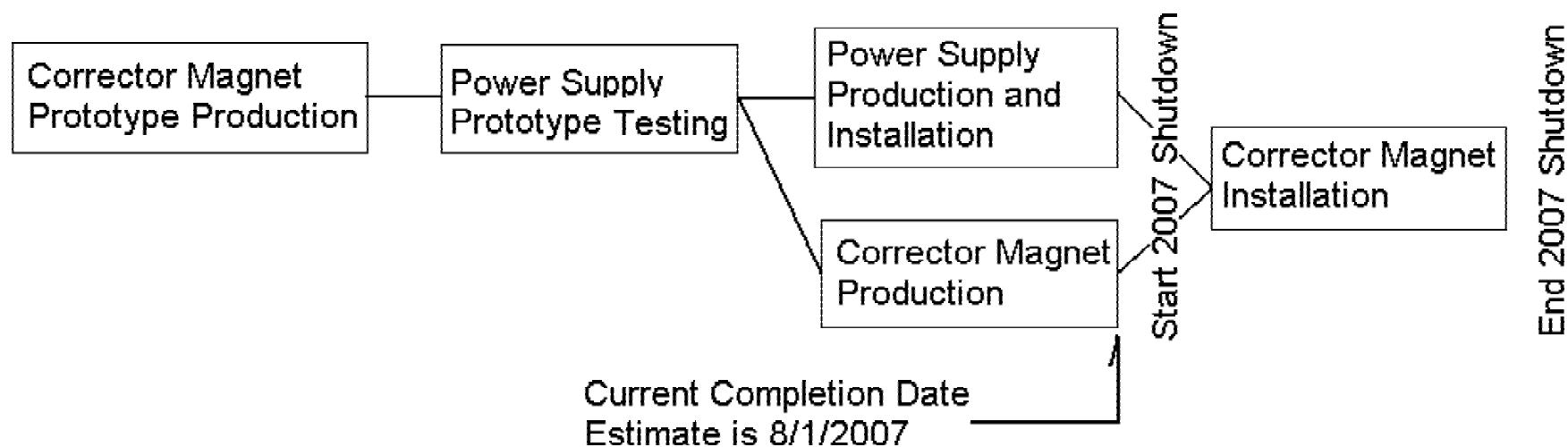
- Schedule 1 of 2 (detailed Gantt chart available)



- 8/16/05

Proton Plan Aug05 Review.mpp

➤ Critical Path(s)



- Corrector Package Performance and Production
 - (Harding)
 - Does not meet magnetic specifications
 - Build prototype and check before committing to production
 - Inadequate design support -> schedule slip
 - Trying to get more help

- Power Amplifier Performance
 - Will we damage the schedule and spend man-hours beyond the budget with a power amplifier that cannot meet the specifications?
 - Output voltage and current ripple must be tolerable
 - Slew rates must be fast with acceptable settling times.
 - The units must hold up to the power cycling and other thermal effects.
 - Reducing This Risk: Procure and test two candidate power amplifiers.
 1. A variation of existing power amplifiers design and supported by AD-AS-ELECTRICAL/ELECTRONIC SUPPORT. This is expected to be less expensive to procure and maintain.
 2. A power amplifier available from an outside manufacturer whose standard product appears to meet our needs. A first article can be purchased right away (10-12 wks ARO).

- Will everything be in place for the 2007 Shutdown?
- Will everything be working for the 2007 START-UP?
 - Scheduling work during the 2007 shutdown is challenging.
 - Old spool pieces in long and short straights must be removed.
 - New corrector spool pieces installed.
 - Correctors cabled, plumbed, surveyed and tested.
 - New BPM's cabled, cable delays matched.
 - Reducing This Risk:
 - Many tasks need not wait for a shutdown. Rack space is available to install and test power supplies and controls.
 - Cable pulls and some plumbing can be done during the 2006 shutdown.
 - Power amplifiers and controls can be debugged with test loads in the gallery.
 - Prototyping of the spool pieces and supports in 2006.
 - Make measurements and drawings for each straight in 2006

- Putting more beam through the Booster means we will need tighter control of our optics to avoid instabilities that cause beam loss and equipment activation.
- The stronger fields and higher slew rates will give us much more control.
- The Corrector Upgrade Projects are among the largest in the Proton Plan.
- The schedule looks do-able.